USAWC STRATEGY RESEARCH PROJECT

ALGAE: AMERICA'S PATHWAY TO INDEPENDENCE

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ABSTRACT

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The United States is dependent on foreign oil to meet 63% of its petroleum demand. As China, India, Japan, and Brazil - all major importers - compete with the U.S. for this finite resource, global demand is growing rapidly. The U.S. consumes 25% of the world's oil, but owns only 4% of the world's known oil reserve. Projections indicate U.S. dependency on foreign oil will continue to increase. Vital interests affected by petroleum dependency include uncertainty of supply, influence of tyrants, rising trade deficits, projected shortage of oil reserves, and concerns of global warming. Oil dependency is an unacceptable risk to U.S. national strategy. This paper advocates independence from foreign oil by converting the national transportation fleet to biodiesel derived from algae; a domestically producible, clean burning, regenerative fuel. Biodiesel can be transported and delivered using existing infrastructure, including America's pipelines, tankers, and the 178,000 gas stations. Among the sources for biodiesel, algae may be the least favored option. Yet, they offer innate advantages as the major source of bioenergy.

ALGAE: AMERICA'S PATHWAY TO INDEPENDENCE

Ensuring a secure supply of energy is a strategic challenge for every country and always a national interest, addressed with political maneuvering. This monograph examines U.S. dependency on imported oil, a growing demand for oil, environmental threat resulting from burning fossil fuels, the projected shortfall in oil supply, and alternatives. Practical realities and their broad impacts are considered. There is a solution, but it requires action. Petroleum dependency can be overcome with large-scale development of biofuel production and refining. Agricultural options, including sugar cane, wheat, corn, and soybeans are considered. In the final analysis, algae are the best choice as a primary source of biofuel. With relatively minor technical obstacles still to be resolved, algae can make the U.S. self-reliant for fuel and significantly reduce the environmental damage caused by burning fossil fuels.

Columbia, Venezuela, Western African countries, former Soviet states, and portions of the Middle East are oil exporting nations with likely ties to organized crime or terrorism. As world demand for oil continues to grow, these oil-exporting countries have more choices regarding trading partners. Leaders of oil-producing countries can afford to turn a cold shoulder to the United States. The U.S. may find itself leveraged by of oil-producing tyrants. Secure access to foreign oil is indeed a U.S. national interest, a reason America fights to maintain a stable Middle East. U.S. oil addiction has led to desperate acts and the use of military force has arguably contributed to terrorist acts against American citizens. The nation is caught in a spiral of economic, environmental, political, and security challenges – but not a conundrum.

U.S. Dependency on Foreign Oil

Annually, an outflow of 150 billion U.S. dollars is spent on foreign oil, adding significantly to the U.S. trade deficit and economic plight.[1] Then, burning the fossil fuel pollutes the environment and adversely affects public health. Each day, the U.S. contributes to global warming by releasing 60 pounds of carbon dioxide (CO_2) for each citizen.[2,3] Yet, these economic and environmental issues are overshadowed by the fundamental strategic weakness of a dependency on imported oil. Without it, the nation simply cannot function.

The U.S., a country with only 2% of the world's conventional oil reserves and 4% of the world's population, consumes 25% of the world's oil.[4] Demanding 20 million barrels per day - importing 63% – it burns and imports more than any other country…and the rate of consumption is growing.[5]

As global demand for oil, during the next 30 years, surpasses the entire volume of oil produced during the last 150 years,[6] the U.S. will be competing with other nations to procure the finite commodity. The Department of Energy (DOE) estimates that by the year 2025 the U.S. will need to import 70% of its oil.

> America imports more than 50 percent of its oil -- more than 10 million barrels a day. And the figure is rising. This is dependence on foreign oil. And this dependence is a challenge to our economic security… And this dependence on foreign oil is a matter of national security. To put it bluntly, sometimes we rely upon energy sources from countries that don't particularly like us.[7]

To mitigate dependency on any one supplier, and the associated vulnerability, the U.S. imported oil from 92 different countries in 2006.[8] However, even with careful managing, "affordable" energy is slipping into history. Oil price is determined, to a large degree, by the "supply and demand" balance. (Geopolitical risk considerations are another important influence.) OPEC's ability to ebb and flow production enables it to influence oil price.[9] Yet, demand is becoming less responsive to movement in price.[10] This trend is indicative of dependence on a scarce resource. The nation, flirting with insensitivity to price, is seemingly resigned to paying a 300% mark-up, even to "friendly" Saudi Arabia where oil extraction rates are between $5 and $15 per barrel, the cheapest production in the world.[11]

The bulk (two-thirds)[12] of petroleum in the U.S. is burned in transportation vehicles. The nation can be weaned from dependency with development of an alternative for powering cars, trucks, trains, and planes. However, *independence from foreign oil* has yet to be identified as a U.S. national interest.

World Dependency on Foreign Oil

Today, oil provides about 40% of the world's energy and fuels 96% of transportation. The increase in the number of cars worldwide will double demand for gasoline by 2020.[13] Oil demand is projected to increase 55% in the first 25 years of the 21st century.[14]

Not until 1994 did China become an importer of oil.[15] Then, within 10 years, China surpassed Japan as the world's second largest importer of oil.[16] Today, China imports *half* its oil;[17] but, with 20% of world population,[18,19] China still consumes only 14 % of world oil.[20] To illustrate China's demand potential: per-capita demand for oil in China is 1/9th that in the U.S.[21] With China's population being three times greater than that of the U.S., if the rate of China's oil consumption continues to grow at the present annual rate, by 2022 China will be consuming the amount of petroleum currently used by the U.S.[22] If China's per-capita oil consumption ever matches that in the U.S., China will be demanding 27 times the oil it uses today. China has already invested significantly in African, Canadian, and South American oil production.[23] The

U.S. and China are *already* competing for the world's finite oil supplies. As demand increases, so will the stakes of competition.

In India, 16% of the world's population consumes only 3% of the world's oil.[24] However, at its current rate of growth, India's oil consumption is doubling every 12 years.[25] Combined, India and China own less than 4% of the world's known oil reserves,[26] yet they account for one-third of the world's population and, within the foreseeable future, will demand most of the world's oil. Secure access to foreign oil is very much a strategic interest for the Far East, too.

This surge of developing countries is fostered, to a large degree, by U.S. desire to increase its own standard of living - the U.S. has moved manufacturing overseas, to reduce costs, so Americans can *buy more for less*, causing marked industrial growth and the corresponding demand for energy.

DoD and Oil

U.S. Department of Defense (DoD) fuel consumption is less than 2% of the country's total.[27] Even so, the U.S. government is the world's largest single user of energy/oil.[28] DoD fuel costs are approaching $15B per year, with roughly 40% for U.S. military transport aircraft and 30% for U.S. Navy ships.[29] This represents a significant portion of these weapons-systems life-cycle costs. In the short run, the price of oil is projected to be a bigger factor than oil availability. A $10 rise per barrel of oil increases DoD fuel costs by $1.3 billion per year. Even though the cost of nuclear propulsion adds "several hundred million dollars" to each ship, $60-a-barrel oil is the tipping point where it becomes more cost effective to operate a Navy amphibious "deep draft" ship on nuclear power. For destroyers, the tipping point is $80 per barrel.[30]

Delivering fuel can be costly, the cost to deliver fuel air-to-air is $20-$25/gallon and the Army front-line delivery cost is $100-$600/gallon.[31] For this reason, in addition to biofuel, there is a strong DoD interest in hybrid technology, alternative fuel, electric fuel cells, reduced size (unmanned), and lighter-weight vehicles for the future inventory.

To guarantee an "assured domestic source" of fuel and a reasonably stable price, the Air Force has been researching alternate fuel sources. In December 2006, the USAF test-flew a B-52 bomber with all eight engines burning a 50-50 blend of JP-8 jet fuel/synthetic fuel made from natural gas with no discernable performance difference. All U.S. services are studying breakthrough technologies *and* seeking options for fuel conservation.[32]

But, DoD consumes only 2% of the total U.S. consumption. Presumably, the DoD can always obtain priority access to oil, so there seems to be no persuasive argument for a DoD fuel shortage. However, U.S. "known" oil reserves, extracted at present production rates, will be depleted within 12 years.[33] Then the U.S. could become completely dependent on imported oil. This may change as new domestic oil sources are presumably found.

Running Out of Oil

There may be vast potential from unconventional oil sources, such as the tar sands and shale in Alberta, which can feasibly be exploited at a cost of just under $70 per barrel.[34] Obviously, for-profit production depends on profitability. Today, as OPEC holds oil prices hovering just under $70 per barrel, profitable extraction of oil from shale using current techniques is questionable.

If production continues at today's rate, many of the largest producers will have lost their relevance as significant world oil suppliers by 2025. Africa, Brazil, China, Mexico, Norway, Russia, and United States will no longer be players. The Middle East will remain as the last big supplier of petroleum and will control the global oil trade.[35]

Assuming consumption rates continue, there are only 41 years of oil remaining.[36] The time is shorter, of course, as consumption rates increase and longer as new oil reserves are discovered. However, we should not assume the world will "run out" of oil in 41 years, because oil producers do not secure reserves for longer than 40 years due to the expense and investment to explore and validate additional reserves. Given the best projection of rates of consumption to known petroleum reserves and estimated future discoveries, no extended world-wide shortage of fossil fuel production is reasonably expected over the next 25 years.[37] However, any projection of an ample world oil supply beyond 2030 is speculative.[38] Without a viable plan for a shift to a alternative, the U.S. will remain oil dependent, even when supply becomes scarce. In the meantime, public awareness of the federal deficit and global warming is growing. As concern increases, the nation's leaders seem to be in denial of the problems.

Independence from Foreign Petroleum

To mitigate disruptions in oil supply, the United States maintains a Strategic Petroleum Reserve. Removing water from naturally occurring subterranean salt domes created these artificial caverns along the Gulf coast of Texas and Louisiana. Topped out, they hold at total of 700+ million barrels of oil – less than 70 days of independence from imported oil and a far cry from oil independence.[39]

For the foreseeable future, fossil energy will remain dominant. In the words of the International Energy Agency's "World Energy Outlook" 2006 report, we are facing "twin energy-related threats:" Not enough oil and too much CO_2: we cannot meet our perceived fossil fuel demand, but we are crippling the environment with our incredible quantity of hydrocarbon emissions.

Michael Klare, author of Blood and Oil: The Dangers and Consequences of America's Growing Dependency on Imported Oil, recently cited five relevant facts: (1) America is absolutely dependent on petroleum. (2) The world is running out of oil. (3) There is extreme global competition to buy oil. (4) Oil exporting countries are increasingly experiencing ethnic conflict, rule by dictators, corruption, danger, and deep hostility towards the U.S. (5) The U.S. practice of using troops to protect oil supplies is "stealing human life for obscene waste." Klare summarized the current position as "futile, dangerous, self-destructive and ineffective," calling for movement towards oil independence.[40]

The Congressional Peak Oil Caucus is concerned enough about petroleum supply to the U.S. that they are calling for a government "crash mitigation program" involving "the total participation of the American public like we had with World War II, the technological focus of the Apollo Moon program and the urgency of the Manhattan project."[41] Reports from the U.S. Department of Energy and the Army Corps of Engineers warn that the time frame to transition from a petroleum-based economy to one based on other forms of energy will take a minimum of 20 years.[42] As we consider a replacement that may not be operational before the world's demand for oil has doubled, the U.S. is becoming *completely* dependent on imported oil. The Middle East will be the sole remaining supplier. It is clearly in our national interest to commit to a non-petroleum energy source delivered by means of the existing infrastructure of pipelines, tanker ships and trucks, filling stations, and engines. It would be preferable if the alternative were renewable and clean burning.

Releasing Sequestered Carbon

Along with other elements, petroleum is made up of carbon. Therefore, as fossil fuels are pumped from a well, carbon is brought up from where it remained sequestered underground for millions of years. When fossil fuel is burned, the carbon is combined with ambient oxygen, forming carbon dioxide (CO_2). Usable oxygen is lost, the formerly sequestered carbon is added to the atmosphere, and greenhouse gas is gained. CO_2, a greenhouse gas, contributes to global warming. A gallon of gasoline weighs 6.3 pounds and amazingly, burning that one gallon of gasoline releases 20 pounds of CO_2 into the atmosphere.[43]

Live plants require carbon (and a small amount of oxygen) to construct carbohydrates. Plants *do* absorb atmospheric CO_2, retaining the carbon and then releasing oxygen during the process of photosynthesis; but plants' absorption rate of CO_2 is only a fraction of the rate released from burning fossil fuels.

Greenhouse Gas

"Greenhouse effect" is a term coined in the mid-1800s by French mathematician Joseph Fourier to describe how the Earth's atmosphere traps heat in gases.[44] By the end of the 1800s, scientists were already speculating on the potential impact of human released CO_2.[45]

In 1957, unprecedented atmospheric build-up of CO_2 was quantified in a publication co-authored by Roger Revelle and Hans Suess. They described how the industrial revolution posed potential risk:

> Human beings are carrying out a large scale geophysical experiment of a kind that could not have happened in the past… Within a few centuries, we are returning to the atmosphere the carbon stored in sedimentary rocks over hundreds of million of years.[46,47]

Revelle identified burning fossil fuels as the major source of the increase in atmospheric CO_2 and stressed human gas emissions would cause global warming. Fifty years after he identified the risk of global warming, the debate over increased CO_2 levels still continues.[48]

While the effects of fossil fuel emissions are debated among politicians, consensus among scientists is that "greenhouse gas" emissions adversely affect the environment and human health. References to greenhouse gases usually focus on CO_2. Other gases are involved, but CO_2 is by far the most significant.[49]

Greenhouse gases allow light from the sun to penetrate the atmosphere, but then they trap a portion of "outward-bound" infrared radiation, warming up the air. Some greenhouse gas is beneficial. Without it, the earth's surface would have an average temperature near 0°F. But due to increasing concentrations of human induced of greenhouse gases, the Earth's average temperature is rising.[50]

The degree of harm of global warming cannot be precisely measured nor agreed upon, but the quantity of emissions is known - and it is vast. The U.S. releases 2.4 billion tons of carbon into the atmosphere each year.[51] That translates to 152,200 pounds every second - the weight of an Abrams tank.

As long as fossil fuels are burned, greenhouse gases will continue to be added to the atmosphere. To curb global warming, countries must make a major commitment to identify and adopt renewable energy sources that add little or no additional carbon to the atmosphere. Since biofuels are derived from *recently* living organisms, burning biofuel does *not* increase the net atmospheric CO_2. Instead, this renewable energy source *recycles* atmospheric carbon, the plant absorbs carbon from the atmosphere as it grows; then, after refining, the biofuel is burned and the carbon is returned to the atmosphere.

Awareness of the need to commit to an alternative to fossil fuel is stimulated by U.S. strategic weakness due to dependency on imported oil, the economic strain from the annual net outflow of $150 billion, and the damage to our environment and health. For a meaningful impact, a renewable fuel should be able to serve as a transportation fuel, where roughly two-thirds of oil is used.[52] A replacement fuel should satisfy three needs: decrease the national dependence on imported oil, better protect the environment and human health, and boost our domestic economy. Biofuel is an alternative meeting these criteria.

<u>Clean, Renewable Fuels</u>

The potential of hydrogen-powered fuel cells is very promising. In the future, this technology may produce energy in virtually unlimited quantities, using renewable resources, and emitting no harmful emissions.[53] Hydrogen receives a lot of attention as an alternative to petroleum and may be the preferred *end-state* fuel for our transportation system; however, as a high-pressure gas (vice a liquid), hydrogen is incompatible with existing distribution pipelines, tankers, fuel stations, and internal combustion engines. In the short term, an impasse exists due to the chicken-or-egg dilemma. What comes first, hydrogen vehicles or hydrogen fuel stations? (For reference, there are currently over 175,000 fuel stations throughout the U.S.[54]) With a single hydrogen pump projected to cost roughly one million dollars, it is impractical to build hydrogen delivery stations preceding demand. Consumers will arguably not buy hydrogen-powered vehicles until the hydrogen fuel is readily available. For compatibility with infrastructure, the best near-term alternative is biofuel.[55]

Ethanol is a biofuel compatible with distribution systems and gasoline engines. At first glance, ethanol seems to recycle carbon – plants absorbing CO_2 and then the ethanol releasing CO_2 emission - and substituting corn ethanol for gasoline appears to reduce emissions by an estimated 18%. But, expand to a broader view to include the entire ethanol production process of plowing fields, planting the corn, manufacturing fertilizer and then spreading it on the field, harvesting, and refining; ethanol does not benefit greenhouse gas emissions. Taking into account the fossil fuels burned during the whole process, the analysis changes to a net CO_2 emission *increase* of 29%. Ethanol actually takes more energy *to produce* than it yields and it inconveniently has less volumetric energy than gasoline. Drivers would be unlikely to desire to fill up solely on ethanol - it contains only two-thirds the energy of gasoline.[56] Miles per gallon (or miles per tank of fuel) drops in the same percentage. (From a DoD perspective, that translates to 1.5 times the fuel delivered to the front lines.) It is highly flammable, making it dangerous to handle and transport. Presently, ethanol provides less than 2% of the U.S. transportation fuel, but that 2% requires a remarkable 14% of the entire U.S. corn production.[57] While farm lobbyists support ethanol because it increases demand for corn, if 100% of U.S. corn crop were directed to ethanol production, the nation would have no corn for food and the ethanol produced would satisfy a mere 14% of U.S. transportation requirements. Corn-based biofuel does support American agriculture, but it can only slightly help reduce dependence on foreign oil and does not mitigate greenhouse gases.[58] Support of corn-based ethanol seems to be motivated by profits (increased demand for corn and ethanol refining) or ignorance, rather than science.

Plants use photosynthesis to convert solar energy into chemical energy in the form of oils, carbohydrates, and proteins. The more efficiently a plant can convert solar energy, the better it serves as a candidate for biofuel (a form of stored solar energy) production. An acre of rapeseed could provide about 100 gallons of biofuel per year, so fueling the country would require 1.4 billion acres of rapeseed fields, considerably more than the 400 million acres currently cultivated. Using rapeseed to power our nation's transportation fleet would create an "environmental catastrophe."[59]

Soybeans are an improvement, yielding about 300 gallons of biofuel per acre per year, but still falling well short of being able to provide the need.[60] Oil palms provide enough oil to produce about 500 gallons per acre, but they require a tropical climate, and the demand for large-scale oil palm production is resulting in clear-cutting of forests, as evidenced in Malaysia and Indonesia.[61]

Algae are some of the most photosynthetically efficient plants.[62] Compared to traditional crops, algae are up to 50 times more productive as a source of biomass.[63] Algae can yield 10,000 – 20,000 gallons of biofuel per acre per year.[64] Algae have the potential to meet the demands of a biofuel-based transportation fleet without monopolizing cultivated land. Also, some varieties can be grown in salt water, easing the concern of a strain on freshwater resources.

Biodiesel: Superior to Ethanol

All plants convert the sun's energy and CO_2 into proteins, starches (sugars), and lipids (oils). All three are equally necessary in forming the structure of a plant cell. But, different plants make varying ratios of these. Ethanol is produced from the sugars in plants (e.g., corn and sugar cane) and biodiesel from oils in plants (e.g., rapeseed, soybean, oil palm, algae). All else being equal, biodiesel requires less energy to produce than ethanol and contains more energy per gallon. Coincidently, diesel engines are generally 60% more efficient and are much simpler than gasoline engines.[65] A switchover to biodiesel would not require any new technology and would not reduce a vehicle's driving range. Biodiesel provides more energy per unit than gasoline; it is only two percent less fuel efficient than petroleum-based diesel.[66]

Biodiesel can be transported, stored, and delivered using existing infrastructure and would be an economic boon for both agriculture and development of refineries. Like ethanol, biodiesel can be blended in any proportion with its petroleum counterpart with little or no engine modifications. When biodiesel is blended with petroleum diesel, the amount of biofuel in the mix is described by the "B" factor. For example, the most common blends of fuel contain 20% biodiesel, labeled B20.[67] In pre-1992 engines, fuel mixtures above B20 can soften and degrade certain elastomers and rubber components over time, such as gaskets, fuel hoses, and fuel pump seals. Newer engines are manufactured with a product non-reactive to biodiesel. Biodiesel has a high affinity to absorb water; this can cause fuel starvation, internal corrosion, and microbial growth in an engine. Water affinity can be mitigated with careful production and storage processes. In very cold weather, biodiesel will gel, just as common #2 diesel fuel does. Blends up to B20 are managed with the same fuel management techniques already used for #2 diesel fuel. Research is underway for cold weather blends over B20. Emissions from biodiesel contain more nitrogen oxides than petroleum diesel. These are reduced to below conventional diesel emission levels using catalytic converters.[68]

Blending as little as 1% biodiesel can improve the lubricating characteristics of petroleum diesel by as much as 65%. This is of significant interest because Environmental Protection Agency (EPA) regulations now require ultra-low sulfur diesel fuels, which can have poor lubricating properties.[69] Pure biodiesel is non-toxic, readily biodegradable, and essentially free of sulfur, the major component of acid rain.[70] Compared to conventional diesel fuel, biodiesel's emissions reduce CO_2 by 78%; reduce unburned hydrocarbons (contributors to smog and ozone) by 67%; reduce carbon monoxide (poisonous gas) by 48%; and reduce particulate matter (airborne hazard to human health) by 47%.[71] Biodiesel has a higher flash point than petroleum diesel, 260-300 degrees versus 125 degrees Fahrenheit,[72] so it is safer to transport. Of course, biodiesel recycles carbon. Already registered as a fuel and as a fuel additive with the EPA, biodiesel also meets the California Air Resources Board's clean diesel standards, offering an immediate transition to a cleaner burning transportation fleet. With a relatively easy conversion, biodiesel can also replace heating oil for domestic and commercial boilers.

Worldwide agriculture now provides the food to feed six billion people. By the year 2050, the global demand on agriculture will increase to feed nine billion people. Raising food production to feed 50% more people presents an enormous challenge. Converting cropland from food production to biofuel poses a serious threat to food security. The best strategy for widespread adoption of biofuel requires an unconventional crop with a very high yield per acre, thriving on non-arable land.

An Answer in Algae

This single-celled plant has the potential to trim greenhouse gases and transform politics and economics. Algae technology provides multiple benefits. It enhances energy security with the potential of enabling the U.S. to meet our *own* demand for transportation fuel and home heating oil. It benefits the environment by serving as a recycling program for carbon waste produced from fossil fuel combustion, it can capture the CO_2 generated by power plants and re-using this greenhouse gas. Algae can be grown using water and land unsuitable for other uses, so algae farms do not compete with crops for arable land or irrigation water.[73]

In 1978, the DOE initiated the Aquatic Species Program to develop renewable transportation fuel, focusing on algae as the source. The DOE program used mostly high oil-content algae grown on waste CO_2 emissions from coal-fired power plants. Algae were chosen because of their capability to remarkably and rapidly convert CO_2 into natural oil. They have the ability to grow under extremes of temperature, pH, and salinity. The project found that some of the algae with high oil content were ideal for biodiesel production. Growth rates were extremely fast and oil content exceeded 50%. Power plant nitrous oxide emissions decreased as much as 85% and carbon dioxide 40% when bubbled through water containing the algae.[74] Algae based fuels were shown as a clean-burning alternative to petroleum in the transportation sector.[75]

Over 3000 strains of algae were studied. Researchers refined the sample to the 300 most-promising species. This collection of untapped resources is currently housed at the University of Hawaii and is still available to researchers.[76]

With sites in California, Hawaii, and New Mexico, the Aquatic Species Program demonstrated the feasibility of large scale, long term, reliable production of algae. A full year of operations of 1000 m^2 open ponds in New Mexico proved extremely high efficiency of CO_2 utilization from power plant emissions. While the desert conditions provided ample sunlight, low temperatures hampered consistently high productivity, particularly at night.

Although analysis demonstrated significant potential for production of biodiesel using algae, in 1995 the cost of producing biodiesel was estimated at $50 per barrel. Petroleum was selling at $20 per barrel – with cost predicted to *remain flat* until 2015. Accordingly, biodiesel was determined *not* economically viable. Budget cutting eliminated federal funding for algae research. Prior to funding cuts, the program estimated that algae farms could *completely* replace petroleum as transportation fuel and heating oil[77] and the abandoned Aquatic Species Program established that neither technology nor resource limitations are legitimate arguments against producing biodiesel from algae.[78] With strong lobbying from agriculture, federal research funding focused towards corn ethanol.

Today, algae biotechnology is back up and running, sponsored by venture capitol, on Vassar Street in Cambridge atop the Massachusetts Institute of Technology (MIT) cogeneration facility. Algae are fed by the plant's exhaust fumes. They absorb smog-producing nitrogen oxides, CO_2 and sunlight, thereby producing oil. Dr. Isaac Berzin, founder of GreenFuel Technologies, is the chemical engineer running the experiment. He resumed research where the canceled DOE's Aquatic Species Program left off.

Berzin reapplied the idea of using algae for scrubbing power plant exhaust with a practical twist. Instead of using a pond, Berzin put the water and algae in tall, thin, transparent cylinders and bubbled exhaust through them; turning a power plant into clean, green generator with a co-located algae farm.[79] In a single pass through an eight foot tall column of water, the algae consume up to 85% of the nitrous oxide and 40% of the CO_2. The required sunlight has been captured using parabolic dishes and delivered via fiber optics.[80] Doubling their mass every few hours, during their one-day lifespan they breathe in pollutants and exhale oxygen as waste.[81] When they die, they are drained from the pipes and the harvested "biomass" is dried with excess heat from the plant's exhaust. The naturally oil saturated algae can be burned in place of coal or refined into biodiesel.[82] Thus they benefit human health and the environment, while enabling "industry to profit from waste."[83]

Berzin calculates that one 1,000 megawatt power plant could produce more than 40 million gallons of biodiesel and 50 million gallons of ethanol per year. Production would require a 2,000 acre "farm" of algae-filled tubes near the power plant. There are nearly 1,000 power plants nationwide with enough nearby space to grow algae.[84]

Production cost of biodiesel is estimated to be roughly $70 per barrel.[85] If oil costs were projected to stay above $70 per barrel, biodiesel production would be of interest to for-profit companies. GreenFuel Technologies is betting on the profits. It has $11 million in venture capital and is conducting a field trial at an unnamed power plant. It expects to expand its demonstration projects and be producing at pump prices comparable to petroleum diesel by 2009.[86]

To completely replace petroleum based transportation fuels currently being used, Michael Briggs, a diesel advocate at the University of New Hampshire, has estimated the U.S. would require about 140 billion gallons per year.[87] (If hybrid use increases, this demand would decrease.) This assumes Americans would switch, over time, to diesel vehicles The main issue is whether the U.S. is able to grow enough crops to provide the vegetable oil for producing this quantity of biodiesel. To grow enough algae to replace all petroleum fuels, Michael Briggs estimated that ponds to grow the algae would require 15,000 square miles (consistent with National Renewable Energy Laboratory research)[88] at a cost of roughly $308 billion. Then, to yield the oil feedstock for the entire country, he has calculated the *operating costs* for the algae farms to be as low as $46 billion per year.[89] While this is a huge commitment, it offers a solution to a national strategic weakness and is comparable to current spending. For reference, the U.S. consumes approximately 4.4 billion barrels per year for transportation.[90] Assuming an oil price of $60 barrel, the U.S. spends $260 billion per year purchasing crude oil for transportation fuel.

Complimentary Programs

Switching the nation's entire transportation fleet to Plug-in Hybrid Electric Vehicles (PHEVs) would decrease America's oil consumption by 70%, completely eliminating the need for petroleum imports; and help reduce the release of sequestered carbon and the depletion of breathable oxygen. PHEVs, like conventional gasoline-electric hybrid vehicles, combine internal combustion engines with electric motors to maximize fuel efficiency. But, PHEVs use larger batteries that are recharged nightly from a standard household 110-volt outlet at a cost estimated to be 5 to 20 cents. PHEVs are able to travel 20 to 30 miles on batteries before the engine engages, thereby providing zero-emission short commuting and increasing fuel economy to 80-160 miles per gallon. Petroleum demand would drop even further if PHEVs were fueled by biodiesel. Existing technology has profound implications: It could eliminate U.S. dependency on foreign oil and reduce greenhouse emissions and smog.[91]

California's governor, a cheerleader for biofuel, wants 4% of his state's electricity to be generated from biomass by 2010.[92] Within 15 years, Germany plans to generate 20% of its electricity from renewable sources. Sweden intends to divest itself from fossil fuels entirely.[93] Meanwhile, in the United States, government funding for energy research and development has dropped from $12 billion to $4 billion.[94] Scientific American recently published that, to stabilize the CO_2 in the atmosphere, R & D of renewable energy programs would require a public funding level of $15 billion to $30 billion a year.[95]

Commitments to develop a responsible, sustainable energy cycle could be funded using market-based schemes, whereby the price of fossil fuels reflects their social costs. The huge tolls of fossil fuels on society include health care expenditures for ailments caused by air pollution, military spending to maintain secure supplies of oil, and environmental and economic damage due to global warming and acid rain. A fee on the release of sequestered carbon would provide a logical means to reward renewable, clean energy. A cap-and-trade program would set emission limits on carbon and enable clean-energy suppliers to sell credits to their dirtier competition.[96]

Conclusion

U.S. strategy for dealing with the nation's petroleum dependence is being addressed ambiguously. The country absolutely needs an energy policy. Senior leaders should stay mindful to the implications of: (a) 25% of the national deficit is spent importing oil. (b) Domestic oil production capability is limited. (c) Instability within oil exporting regions. (d) U.S. oil reserves are marginal. (e) Fossil fuels are changing the earth's climate.

The U.S. needs to develop the national will to rally from this perilous position, embracing an education initiative to stimulate public understanding, interest, and activism. Americans need to understand the political, social, health, and environmental implications of the nation's oil dependency. The country needs clean, renewable fuel sources.

Oil prices are held at a ceiling by OPE to foul interest for investment in alternate forms of energy.[97] Development of non-petroleum fuels by private industry is not likely. Government leaders must respond to this strategic challenge as the catalyst for change, establishing conclusive goals, initiating investments in R & D, tax incentives, and regulations - setting a standard for environmental responsibility and leading the world to a better future.

The U.S. cannot afford to continue burning petroleum until a zero-emission fuel is developed. It must seize the interim opportunity to recycle carbon, producing fuel from plants grown in an environment *not* competing with food production. Of all the near-term options considered, algae are probably the least favored current option. Yet, they offer the innate advantages to be embraced as the major source of bioenergy.[98]

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